THE COMPARISON OF MONOCHROMATIC X-RAY SOURCES BASED ON X-RAY TUBE AND 5 MEV MICROTRON FOR POSSIBLE APPLICATION IN MEDICINE*

A.P. Potylitsyn, Yu.A. Popov, A.V. Vukolov, I.V. Zaitsev and A.R. Wagner [#],
Tomsk Polytechnic University, 30, Lenin av., Tomsk, 634050, Russia
V.N. Zabaev, Nuclear Physics Institute, 2a, Lenin av., Tomsk, 634050, Russia

Abstract

With progress of accelerator and computer techniques a question about using of the monochromatic X-ray sources for medicine diagnostic purposes becomes more and more actual.

In principle the monochromatic X-ray radiation may be generated using X-ray tube and crystal-monochromator. Nevertheless even using modern X-ray tubes with rotating anode it is impossible to generate the flux density of monochromatic radiation of required intensity.

INTRODUCTION

For today as the monochromatic X-ray source is showed quite a few types of different projects. It is from very expensive in making and exploitation setups such as monochromatic beam of synchrotron radiation, free electron laser and more inexpensive projects such as parametric X-ray radiation on electrons, protons, nuclei and different energies of charged particles and others [1-4]. This paper reviews about bremsstrahlung diffraction for the X-ray source creating purposes based on the compact cheap accelerators.

The photon energy of diffraction bremsstrahlung (DBS) is determined by Bragg equation:

$$E_n = n\frac{2\pi\hbar c}{2d\sin\theta_B}, \qquad (1)$$

where E_n is the photon energy, n is the diffraction order, d is the interplanar spacing, θ_B is the angle between the crystal plane and the particle momentum (Bragg angle). One can readily see that change the angle of crystal orientation (eq. 1) to reduce to change wavelength of monochromatic radiation. Therefore present mechanism to be of interest as a tunable monochromatic X-ray source.

EXPERIMENT AND RELATS

In the paper for comparison out clearly of monochromatic X-ray different sources two experiments is shown on bremsstrahlung diffraction of microtron and X-ray tube. In both cases the same experimental setup (crystals, registration system and analogous geometry) is used.

Information about the first experiment which are described in this paper one can find in detail in the work [5].The experiment was carried out at the microtron of NPI TPU, Tomsk. The geometry of experiment is showed in Figure 1.

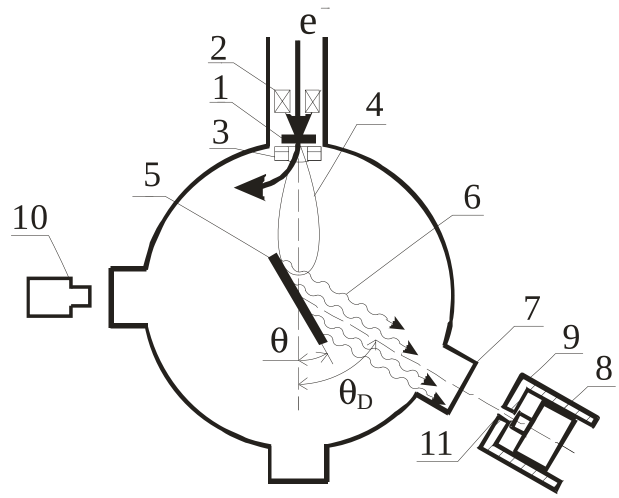

Figure 1: Equipment layout.

1 – aluminum converter (thickness 125 μm), 2 – pick-up coil, 3 – deflecting magnet, 4 – bremsstrahlung beam, 5 – crystal fixed on goniometer, 6 – diffracted X-ray radiation, 7 – kapton window (thickness 150 μm), 8 – semiconductor silicon detector with sensitivity region 13 mm^2, 9 – lead shield, 10 – TV-camera, 11 – collimator.

The bremsstrahlung beam was generated by the electron beam in the aluminium converter (see, point 1 in Figure 1.) and then the charged particles were removed by a magnet (see, point 3 in Figure 1.). Further, the bremsstrahlung photons were diffracted in the crystal (see, point 5 in Figure 1.) in the direction of the detector (see, point 8 in Figure 1.).

In the both experiment was used as monochromator crystals of pyrolytic graphite, germanium and tungsten. The parameters of using crystals are present in table 1.

Table 1: Crystal parameters

Crystal	Linear dimension, mm	Thickness, μm	Mosaisity, mrad
Pyrolytic graphite C (002)	20×30	350	~4
Germanium Ge (111)	20×20	2000	~1
Tungsten W (111)	10×16	100	~0.3

*Work supported by …
[#]Wagner@tpu.ru

During the experiments the DBS photon spectra at various angles of a crystal orientation relative to an axis of the electron beam were registered.

The spectrum of DBS from the pyrolytic graphite for crystal orientation angle $\theta_B = 30°$, $\theta_D = 60°$ is presented in the Figure 2.

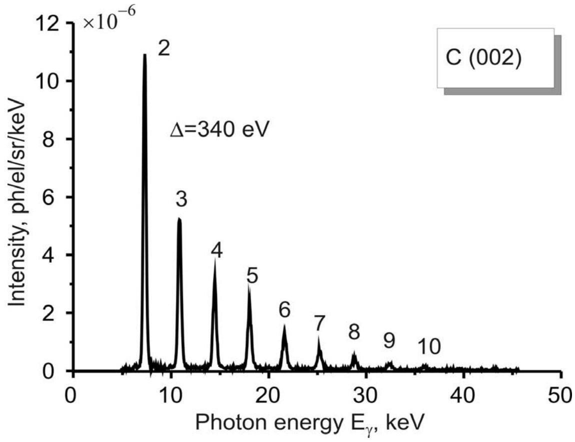

Figure 2: Spectrum of DBS from pyrolytic graphite crystal.

One can clearly see photon diffraction maxima which correspond to (n = 2, 3,…10) diffraction order and (7.46, 11.10,… 37 keV) energy. The FWHM for the second diffraction order was equal to $\Delta = 340\,\mathrm{eV}$. The DBS experimental yield from the pyrolytic graphite crystal for the second diffraction order (n = 2) was equal to about $8.5{\cdot}10^{-6}$ photon/electron/sr taking with into account the intensity loss towards the detector.

The spectrum of DBS from the tungsten crystal W (111) for crystal orientation angle $\theta = 30°$ is presented in the Figure 3.

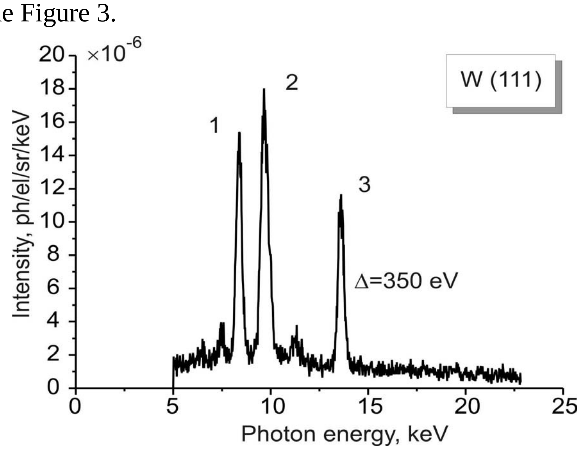

Figure 3: A radiation spectrum from tungsten crystal W (111). Peaks 1 and 2 are characteristic radiation (L-lines); peak 3 is diffraction bremsstrahlung of second diffraction order.

Maximum 3 ($E_\gamma = 13.61\,\mathrm{keV}$) corresponded to the second diffraction order of DBS (the first permitted reflex), maxima 1 ($E_\gamma = 8.39\,\mathrm{keV}$) and 2 ($E_\gamma = 9.67\,\mathrm{keV}$) corresponded to L_α and L_β lines of tungsten characteristic radiation. The measured CXR peaks are interest for independent calibration and absolutization of DBS photon yield. The FWHM for the second diffraction order was equal to $\Delta = 350\,\mathrm{eV}$. The yield of DBS photons in a tungsten crystal was equal to about $7{\cdot}10^{-6}$ photon/electron/sr.

As stated above the second experiment was carried out at the X-ray tube. The geometry of experiment is present in Figure 4. The X-ray beam of X-ray tube was collimated by two collimators (see, point 2, 3 in Figure 4) and then the X-ray photons were diffracted in the crystal (see, point 4 in Figure 4) in the direction of the detector (see, point 6 in Figure 4).

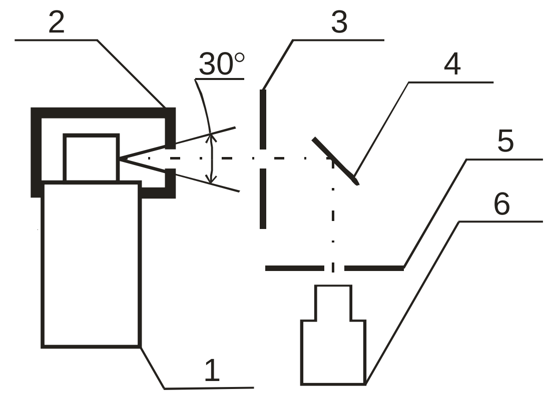

Figure 4: Equipment layout.

1 – X-ray tube, 2 – collimator (∅ 10 mm), 3 – collimator (∅ 10 mm), 4 –crystal fixed on goniometer, 5 – collimator (∅ 3 mm), 6 – semiconductor silicon detector with sensitivity region 13 mm^2.

The detector aperture was defined by the collimator (see, point 5 in Figure 4) which was selected in order to guarantee the optimum rate of detecting system. The optimum size (diameter) of the collimator was chosen so, that a counting rate of the detector was equal to about 5 Hz. This allowed reducing to a minimum a pile-up effect. The angle between X-ray beam and crystal was installed by goniometer (see, point 4 in Figure 4). The parameters of X-ray tube are present in table 2.

Table 2: X-ray tube parameters

Parameter	value	Unit
X-ray tube anode voltage	40	kV
X-ray tube anode current	10	mA
Anode material	Molybdenum	

The spectrum of DBS from the germanium for crystal orientation angle $\theta = 45°$ is presented in the Figure 5. One can clearly see photon diffraction maxima which correspond to (n = 3, 4, 5) diffraction order. The FWHM for the third diffraction order was equal to $\Delta = 350\,\mathrm{eV}$. The DBS experimental yield from the germanium crystal was equal to about $7 \cdot 10^{-12}$ photon/electron/sr taking into account the intensity loss towards the detector.

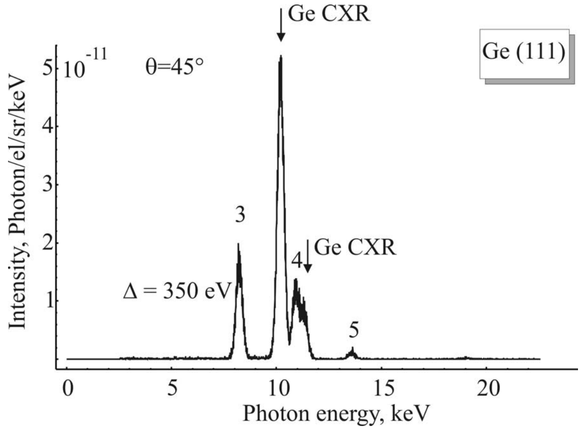

Figure 5: A radiation spectrum from germanium crystal Ge (111).

The spectrum of DBS from the pyrolytic graphite for crystal orientation angle $\theta_B = 50°$ and detector angle $\theta_D = 100°$ is presented in the Figure 6.

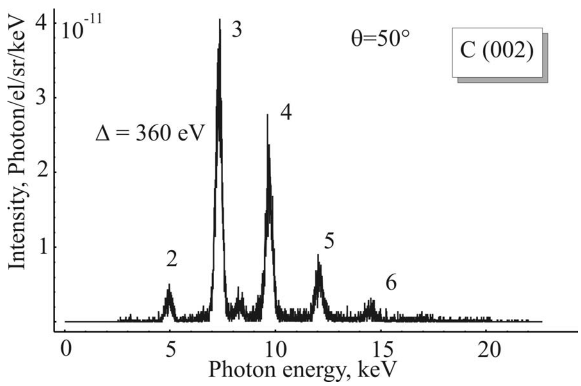

Figure 6: Spectrum of DBS from pyrolytic graphite crystal.

In contrast with fig. 2 there are photon diffraction maxima which correspond to (n = 2, 3, 4, 5, 6) diffraction only. The FWHM for the third diffraction order was equal to $\Delta = 360\,\mathrm{eV}$. The DBS experimental yield from the pyrolytic graphite crystal for the second diffraction order (n = 3) was equal to about $2 \cdot 10^{-12}$ photon/electron/sr taking into account the power loss towards the detector.

For comparison of these both monochromatic X-ray sources the flux density are present in table 3.

CONCLUSION

After comparition one can see, that source based on cheap compact accelerators such microtron is more effective than traditionally using X-ray tubes. But don't forget what such source has a small duty-factor and if it will use during long time than X-ray tube with streaming operation can give larger integration flux.

Table 3: Monochromatic X-ray sources characteristics

Source	X-ray tube	Microtron
Beam current, mA	10	0.3
Crystal (monochromator)	Pyrolytic graphite	
Energy of diffraction maximum, keV	7.9	7.29
Yield, ph/el/sr	$1.3 \cdot 10^{-11}$	$8.5 \cdot 10^{-6}$

Than question is emerges, where is we can use it? The first, it will be use in medicine purpose (for example: radiography and angiography). As is well known to obtain one image the exposure time during coronary angiography is ~ 1 ms.

Table 4: Flux density per 1 ms.

Source	X-ray tube	Microtron
Time	1 ms	0.6 μs*
Yield, ph/sr	$1.5 \cdot 10^{3}$	$1.6 \cdot 10^{10}$

* operating mode of microtron is 25 Hz, spill is 0.6 μs

But for exposure one image in radiography is needed the flux density about 10^{14} ph/sr. This difference is possible partly compensate using modern digital systems of radiography which allow to reduce value of the flux density on 1.5, 2 order of magnitude.

In case radiography such source is very important in respect to reduce a radiation dose obtained by patient on estimate it more then two order of magnitude [6] and to improve contrast of a obtained image[2].

Compact electron accelerators for energy range less than 30 MeV (for ex. linac, microtron, betatron) may be used for monochromatic X-ray beams obtaining. It can be a big deposit in evolution of scientific and technique especially in medicine field.

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